

Method of Manufacturing Glass Optical Elements

[0001]

[Field of the Invention]

The present invention relates to a method of manufacturing glass optical elements by molding glass materials with high surface precision, including lenses in which one or both surfaces are concave. In particular, the present invention relates to a method permitting the manufacture of glass optical elements by molding glass materials with high surface precision, including lenses having a ratio b/a of the peripheral thickness b to the center thickness a of at least 1.5.

[0002]

[Background of the Invention]

Methods in which softened glass is pressed with a forming mold having a shape identical or similar to that of a product to directly manufacture lenses without grinding or polishing (high-precision pressing methods) are widely utilized. Since high-precision pressing permits the manufacturing of large quantities of lenses of both spherical and aspherical surfaces at low price, it is employed to manufacture the optical system lenses of a variety of optical equipment and products such as digital cameras and video cameras. In recent years, demands have been made of high-precision pressing to manufacture lenses that are large and difficult to mold.

[0003]

However, in lenses in which one or both surfaces are concave and in lenses in which there is a large difference in thickness between the center and the edge (rim) portions of the lens, once molded surfaces are transferred to the glass by the pressing process, the transfer surface often deforms during cooling and removal from the forming mold or during annealing, making it impossible to obtain a lens of desired surface shape. This is particularly acute in lenses having two concave surfaces with a large difference in thickness between the center and edge portions.

[0004]

Japanese Unexamined Patent Publication No. Hei 7-267658 describes a method of molding concave meniscus lenses in which a glass material in a softened state is pressed to obtain a glass optical element wherein the pressed glass is maintained at a certain temperature at or above the glass transition temperature for a prescribed time in a cooling step. While this method is principally directed to removal of the thermal stress that has been generated in the glass material within a short period, it does not permit the molding of lenses with desired surface shapes that are particularly hard to achieve, which are those the present invention focuses upon.

[0005]

[Summary of the Invention]

Accordingly, an object of the present invention is to provide a method of manufacturing glass optical elements such as glass lenses by press-molding glass materials with high precision, including lenses that are concave on one or both surfaces and have a large b/a ratio, where a denotes center thickness and b denotes peripheral thickness.

[0006]

Research conducted by the present inventors resulted in the discovery that by subjecting a molded product in the form of a lens to a prescribed pressure within a certain temperature range after the press-molding and up to the removal from the forming mold, the above-stated problem was solved; the present invention was devised on this basis.

[0007]

The present invention relates to a method for manufacturing a glass optical element comprising steps of:

molding a glass material softened by heat with a forming mold which comprises an upper mold and a lower mold, each having a molding surface so that optically functional surfaces are formed on the glass material by applying a molding pressure,

cooling the glass material so that the glass material obtains a

predetermined viscosity, and

removing the cooled glass material from the forming mold,

wherein a temperature of the glass material is maintained, in the cooling step, within a range of (T_g+30) to (T_g-50) degree centigrade at least for a predetermined time, and a secondary pressure is applied to the glass material at least during the predetermined time, so that the strain in the glass material is reduced,

where T_g represents glass transition temperature of the glass.

[0008]

[Brief Description of the Drawings]

Fig. 1 shows typical changes over time in temperature and pressure in the manufacturing method of the present invention.

Fig. 2 is a drawing descriptive of a concave meniscus lens comprising a flat portion perpendicular to the optical axis on the outside of one of the optically functional surfaces.

Fig. 3 is a schematic drawing of the molding device employed in Examples 1-3.

Fig. 4 is a descriptive drawing of the glass lenses manufactured in Examples 1 and 2.

Fig. 5 shows the changes over time in temperature and pressure applied in the forming mold of Example 1.

Fig. 6 shows the changes over time in temperature and pressure applied in the forming mold of Example 2.

Fig. 7 shows the maintenance time required to achieve not greater than 0.5 irregularities when manufacturing the lenses of different rim thickness, center thickness, and outer diameter of Example 3.

[0009]

[Detailed Explanation of the Invention]

The method of manufacturing glass optical elements of the present invention comprises the steps of:

molding a glass material softened by heat with a forming mold which

comprises an upper mold and a lower mold, each having a molding surface so that optically functional surfaces are formed on the glass material by applying a molding pressure,

cooling the glass material so that the glass material obtains a predetermined viscosity, and

removing the cooled glass material from the forming mold.

[0010]

In the molding step, a softened glass material is subjected to pressure in a forming mold comprising an upper mold and a lower mold having forming surfaces for the forming of optically functional surfaces on a glass material to transfer shapes of said forming surfaces to said glass material.

In the cooling step, the forming mold is cooled, for example, until the glass to which said forming surfaces have been transferred reaches a prescribed viscosity.

In the removal step, the cooled glass is recovered from said forming mold.

[0011]

In the cooling step of the manufacturing method of the present invention, a temperature of the glass material is maintained within a range of (Tg+30) to (Tg-50) degree centigrade at least for a predetermined time, and a secondary pressure is applied to the glass material at least during the predetermined time, whereby the strain in the glass material is reduced. That is, the glass material is subjected to post pressing in the cooling step and internal distortion of the glass produced by cooling is alleviated by maintaining the glass within the prescribed temperature range.

[0012]

In the method of the present invention, it is preferred that the secondary pressure is substantially continuously applied, following the application of molding pressure and up to the removing. That is, the post pressing is conducted so as to begin without interruption of pressure following pressing to transfer forming surfaces.

[0013]

It is also preferred that the secondary pressure is preferably smaller than the molding pressure and that the secondary pressure is set at pressure P1 before the beginning of the predetermined time and the secondary pressure is set at pressure P2 during the predetermined time, where P2 is greater than P1.

In a preferred embodiment of the present invention, temperature variation of the glass material of which temperature is maintained in the cooling step is preferably 5 degree centigrade per minute or less, and more preferably substantially null.

[0014]

In another preferred embodiment of the present invention, in the cooling step, the temperature of the glass material is maintained within (Tg) to (Tg-50) degree centigrade, preferably (Tg) to (Tg-20) degree centigrade at least for the predetermined time and temperature variation of the glass material of which temperature is maintained in the cooling step is 5 degree centigrade per minute or less.

In still another preferred embodiment of the present invention, the secondary pressure is preferably started to apply when a center thickness of the glass material is within $\pm 0.2\text{mm}$ range of the glass optical element.

[0015]

The manufacturing method of the present invention will further be described in view of Fig. 1.

First, softened glass material is pressed with a forming mold and forming surfaces of the forming mold are transferred to the glass material. The glass material may be a glass preform that has been molded in advance to a prescribed shape, or a glass gob. The glass material may, for example, be double-convex in shape. A glass material is employed that has been adjusted (softened) to a temperature suited to press-molding. The glass material may be in the form of a glass preform or a glass gob that has been prepared from molten glass and is employed without returning it to room temperature. Alternatively, the glass material may also be in the form of a glass gob or a

glass preform that has been returned to room temperature and then softened by reheating.

[0016]

The forming mold comprises an upper mold and a lower mold. So long as the forming mold comprises an upper mold and a lower mold, each having a forming surface forming optically functional surfaces on the glass material, there are no particular restrictions. Known forming molds may be suitably employed with or without further modifications.

[0017]

The concave meniscus lens and double-concave lenses that are manufactured by the manufacturing method of the present invention have optically functional surfaces (optically effective regions) for incorporation into various lens systems. For example, the concave surface denoted by 41 in Fig. 2 is such a surface. In this case, flat portion 43 perpendicular to the optical axis is provided on the outside of concave surface 41.

The conditions under which the softened glass material is pressed in the forming mold (temperature of the glass material and forming mold, pressing temperature and time, and the like) may be suitably determined in consideration of the shape of the glass being formed or the like.

[0018]

Following press-molding, the forming mold is cooled until the glass to which shapes of the molding surfaces have been transferred reaches a prescribed viscosity.

Cooling of the forming mold begins either simultaneously with the start of application of pressure for press-molding, during press-molding, or upon completion of press-molding.

Following cooling of the forming mold to a prescribed temperature, the molded glass is removed from the forming mold.

[0019]

In the manufacturing method of the present invention, post pressing of the glass to which the shapes of the molding surfaces have been transferred is

preferably conducted from the completion of the application of pressure for press-molding to removal of the glass material from the forming mold. Post pressing, application of the secondary pressure, is begun when the glass to which the shapes of the molding surfaces have been transferred reaches substantially the same thickness as the targeted glass optical element. The substantially same thickness means that a center thickness of the pressed glass material is within $\pm 0.2\text{mm}$ range of a center thickness of the glass optical element. During the cooling step, the molded glass is temporarily maintained within a prescribed temperature range for a prescribed period.

[0020]

Preferably, post pressing is continuously conducted from the completion of press-molding so that pressing is uninterrupted. That is, after press-molding, post pressing begins without complete release of pressure for the press-molding. Further, the temperature of the molded glass material is maintained within the prescribed range for a prescribed period at any time during the cooling step. This state will be described in view of Fig. 1.

[0021]

A softened glass material of temperature t is subjected to a pressure P to transfer the shapes of the molding surfaces. P , as the load, may be suitably selected based on the viscosity of the glass material, the shape of the lens to be obtained, or the like. Examples are 9.8×10^4 - 294×10^4 Pa, preferably 9.8×10^4 - 196×10^4 Pa.

[0022]

Following press-molding at pressure P , pressing is continued at pressure P_1 without ever completely removing pressure. Following the end of press-molding at pressure P , the forming mold is cooled (primary cooling). However, primary cooling may begin simultaneously with press-molding or during press-molding. Primary cooling can be conducted at a relatively rapid cooling rate generating internal distortion in the molded glass; for example, 10 degree centigrade/min or more, preferably 10-300 degree centigrade/min, and still more preferably, 30-200 degree centigrade/min.

[0023]

Once the forming mold has been cooled by primary cooling to a prescribed temperature of t_1 , it is subjected to pressing at a prescribed pressure P_2 . However, cooling of the forming mold, as set forth above, may begin either simultaneously with the start of press-molding or during press-molding.

[0024]

Although pressures for pressure P_1 and pressure P_2 shown in Fig. 1 are different, they may be a single identical pressure. Further, the temperature during pressing at prescribed pressure P_2 may be constant at t_1 , or may be gradually decreased from t_1 . The temperature during pressing at prescribed pressure P_2 is conducted under conditions alleviating the internal distortion generated in the molded glass by the primary cooling. For example, cooling may be conducted at 0-5 degree centigrade/min, preferably about 0 degree centigrade/min.

[0025]

The temperature range that is maintained at least for a predetermined time runs from a temperature of 50 degree centigrade below the glass transition temperature (T_g) of the glass optical element (T_g-50 degree centigrade) to T_g+30 for the following reasons. This temperature range permits alleviation of internal distortion causing surface shape deterioration of the lens once the lens has been removed from the mold while maintaining the surface shape that has been obtained by transferal of the molding surfaces. Further, alleviation of internal distortion within the above temperature range inhibits the generation of new internal distortion during the subsequent step of cooling to the removal temperature.

[0026]

The above-stated temperature range that is to be maintained is preferably (T_g-50 degree centigrade) to T_g , and more preferably (T_g-20 degree centigrade) to T_g . From the perspective of improving the final surface shape of the product, starting of the temperature maintenance is desirably at a point

where the temperature of the molded glass material has dropped to T_g or below.

[0027]

After being maintained within this temperature range for a prescribed period, the forming mold is further cooled. Once the molded glass has been cooled to a prescribed viscosity, a viscosity permitting the maintenance of a surface precision where there are not more than 0.8 irregularities, such as T_g -50 degree centigrade or less, for example, to room temperature, the molded glass is removed from the mold. Post pressure P_3 is continuously applied during the period running from maintenance of a prescribed temperature range through to removal. Pressure P_3 may be identical to or different from P_1 and P_2 .

[0028]

Post pressures P_1 , P_2 , and P_3 are suitably loads that make the transferred surface of the glass to which the molding surfaces of the forming mold have been transferred by pressure P continuously retain the shape of the molding surfaces. Specifically, they may be suitably selected in view of the viscosity of the glass at the time maintenance is conducted, the shape of the molding surfaces, and the like. Normally, for post pressures P_1 , P_2 , and P_3 , pressures not greater than P are desirable from the perspective of maintaining the formed shape. However, P_1-P_3 are preferably pressures that change little the thickness of the glass that has been molded by pressure P . Specifically, the change in thickness due to P_1-P_3 falls within the center thickness tolerance of the lens that is obtained, for example, ± 0.03 mm, preferably about 0.001-0.12 mm.

[0029]

Further, P_2 is conducted at a load capable of alleviating internal distortion within the glass while applying a pressure causing the transferred surfaces of the glass to which the molding surfaces of the forming mold have been transferred to retain the shape of the molding surfaces. Specifically, this pressure may be suitably selected based on the viscosity of the glass at the

time and the shape of the molding surfaces.

When P2 is excessively low, pressing in a state retaining the particular shape becomes difficult. This tends to result in the development of partial or total irregularities.

By contrast, when the load of P2 is excessively high, internal distortion within the glass tends not to be alleviated and sometimes fails to be alleviated to a degree adequate to maintain the shape of the lens removed from the mold. As a result, irregularities tend to develop near the optical center of the molded glass.

[0030]

The post pressing conditions (pressure and temperature) and the maintenance conditions (temperature range and time) are suitably set to keep the irregularities observed in the molded glass to not greater than one, preferably not greater than 0.5, and more preferably not greater than 0.3.

[0031]

Maintenance time t_1 during the cooling step desirably falls within the following range when the center thickness of the glass optical element, the product, is denoted as a and the peripheral thickness as b :

when $1.5 \leq b/a < 2.0$, $0 < t_1 \leq 120$ seconds, preferably $10 < t_1 \leq 120$ seconds,
more preferably $20 < t_1 \leq 120$ seconds,

when $2.0 \leq b/a < 2.5$, $20 < t_1 \leq 180$ seconds, preferably $60 < t_1 \leq 180$ seconds,
when $2.5 \leq b/a$,

when $2.5 \leq b/a$, preferably $120 < t_1 \leq 350$ seconds.

[0032]

After maintaining the above-stated temperature, the forming mold is further cooled (secondary cooling). When the molded glass reaches Tg or below, it is removed from the forming mold. The secondary cooling rate may be, for example, 10 degree centigrade/min or more, preferably 10-300 degree centigrade/min, and more preferably 30-200 degree centigrade/min.

[0033]

Post pressing is conducted at pressure P3 during secondary cooling, as

well. Pressure P3 may be identical to P1 and P2 or different. However, P3 is desirably a load that permits pressure application causing the transferred surfaces of the glass to retain the shape of the molding surfaces and that does not generate new internal distortion within the glass. From this perspective, P3 is preferably lower than P1 and P2, with, for example, 0.0098×10^4 - 49×10^4 Pa being preferred, and 0.0098×10^4 - 4.9×10^4 Pa being more preferred.

[0034]

The molded glass obtained by the manufacturing method of the present invention may be a lens having one or two concave surfaces. In particular, the molded glass may be a lens one surface of which is concave surface and the other surface of which is convex (for example, the convex surface may be spherical).

Further, the manufacturing method of the present invention permits the manufacturing of lenses in which the ratio b/a of peripheral thickness b to center thickness a is 1.5 or greater, preferably 2 or greater.

[0035]

[Examples]

The present invention is further described below based on the following Examples.

The molding device shown in Fig. 3 was employed in Examples 1-3.

In the molding device shown in Fig. 3, an upper mold 22 and a lower mold 23 are disposed within a hot molding chamber 21 sealed within a housing 21a. Upper mold 22 and lower mold 23 are secured through adiabatic bases 29 and 30 to the front ends of upper fixed shaft 24 and lower movable shaft 25, respectively. Lower movable shaft 25 is linked to a pressure cylinder, not shown, by which it is driven upward during pressure application.

Further, adiabatic bases 29 and 30 have cooling gas outlets 31 and 32, respectively, for independently cooling upper mold 22 and lower mold 23. The supply of gas can be independently controlled above and below, permitting change in the cooling rates of upper mold 22 and lower mold 23. An inert gas was employed as the cooling gas.

[0036]

Example 1

The glass lens (ratio $b/a=3.5$, oblate spherical lens) of the shape shown in Fig. 4, one surface of which was concave (radius of curvature $R=4$ mm) and the other surface of which was convex (radius of curvature $R=38$ mm) was manufactured. The concave surface was formed with the upper mold and the convex surface with the lower mold. LaC13 ($T_g=520$ degree centigrade, $T_s=560$ degree centigrade) was employed as the glass material.

The basic molding conditions (temperature, pressure, time) are given in Fig. 5, and the detailed molding conditions in Table 1. The results are also given in Table 1. An explanation of ranking of the annealed products is given in Table 2, which is shown in the column of results in Table 1. Examples 1-15 are working Examples of the present invention.

[0037]

Table 1

| Sample | Maintenance time (Second) | Maintenance temperature (°C) | Post-pressurization pressure (Pa) | Results |
|--------|---------------------------|----------------------------------|-----------------------------------|------------------------|
| 1 | 300 | 510 ($T_g-10^{\circ}\text{C}$) | 29.4×10^4 | A |
| 2 | 100 | 510 ($T_g-10^{\circ}\text{C}$) | 29.4×10^4 | A |
| 3 | 100 | 530 ($T_g+10^{\circ}\text{C}$) | 29.4×10^4 | B |
| 4 | 300 | 530 ($T_g+10^{\circ}\text{C}$) | 29.4×10^4 | A |
| 5 | 100 | 510 ($T_g-10^{\circ}\text{C}$) | 14.7×10^4 | C (Circumference part) |
| 6 | 300 | 510 ($T_g-10^{\circ}\text{C}$) | 19.6×10^4 | A |
| 7 | 300 | 530 ($T_g+10^{\circ}\text{C}$) | 19.6×10^4 | B |
| 8 | 100 | 510 ($T_g-10^{\circ}\text{C}$) | 19.6×10^4 | A |
| 9 | 100 | 530 ($T_g+10^{\circ}\text{C}$) | 19.6×10^4 | C |
| 10 | 50 | 510 ($T_g-10^{\circ}\text{C}$) | 29.4×10^4 | A |
| 11 | 50 | 510 ($T_g-10^{\circ}\text{C}$) | 19.6×10^4 | C (Circumference part) |
| 12 | 50 | 530 ($T_g+10^{\circ}\text{C}$) | 29.4×10^4 | B |
| 13 | 50 | 530 ($T_g+10^{\circ}\text{C}$) | 19.6×10^4 | C (Circumference part) |
| 14 | 50 | 490 ($T_g-30^{\circ}\text{C}$) | 29.4×10^4 | B |
| 15 | 50 | 490 ($T_g-30^{\circ}\text{C}$) | 19.6×10^4 | A |

[0038]

Table 2

| Rank | Irregularity |
|------|---------------------|
| A | 0.3 fringes or less |
| B | 0.3-0.5 fringes |
| C | 0.5-0.8 fringes |
| D | 0.8 fringes or more |

[0039]

Example 2

Employing the same glass material and device as in Example 1, a lens was molded by the manufacturing method in accordance with the temperature, pressure, and time scheme given in Fig. 6.

The molding conditions and results are given in Table 3. An explanation of ranking of the annealed product is given in Table 2, which is shown in the column of results in Table 1. Examples 2-8 are working Examples of the present invention.

[0040]

Table 3

| Sample | Maintenance time (Second) | Maintenance temperature (°C) | Post-pressurization pressure (Pa) | Results |
|--------|---------------------------|------------------------------|-----------------------------------|------------------------|
| 1 | 0sec | | | D |
| 2-① | 60sec | 530°C | 39.2×10^4 | C |
| 2-② | 180sec | 530°C | 39.2×10^4 | C |
| 3-② | 180sec | 500°C | 39.2×10^4 | C |
| 4-① | 60sec | 500°C | 29.4×10^4 | C |
| 4-② | 180sec | 500°C | 29.4×10^4 | C |
| 5 | 300sec | 500°C | 29.4×10^4 | A |
| 6 | 300sec | 530°C | 29.4×10^4 | C (Circumference part) |
| 7 | 300sec | 530°C | 39.2×10^4 | B |
| 8 | 300sec | 500°C | 39.2×10^4 | B |

[0041]

Example 3

Employing the same glass material and device as in Example 1, lenses of differing rim thickness, center thickness, and outer diameter were manufactured under the same conditions as in Example 1, and the maintenance times required to achieve an irregularity of not greater than 0.5 were determined. The results are given in Fig. 7.

The present disclosure relates to the subject matter contained in Japanese Patent Application No. 2000-265300 filed on September 1, 2000, which is expressly incorporated herein by reference in its entirety.